Electroweak Physics Prospects in Run 2 with the DØ Detector at the Tevatron Collider

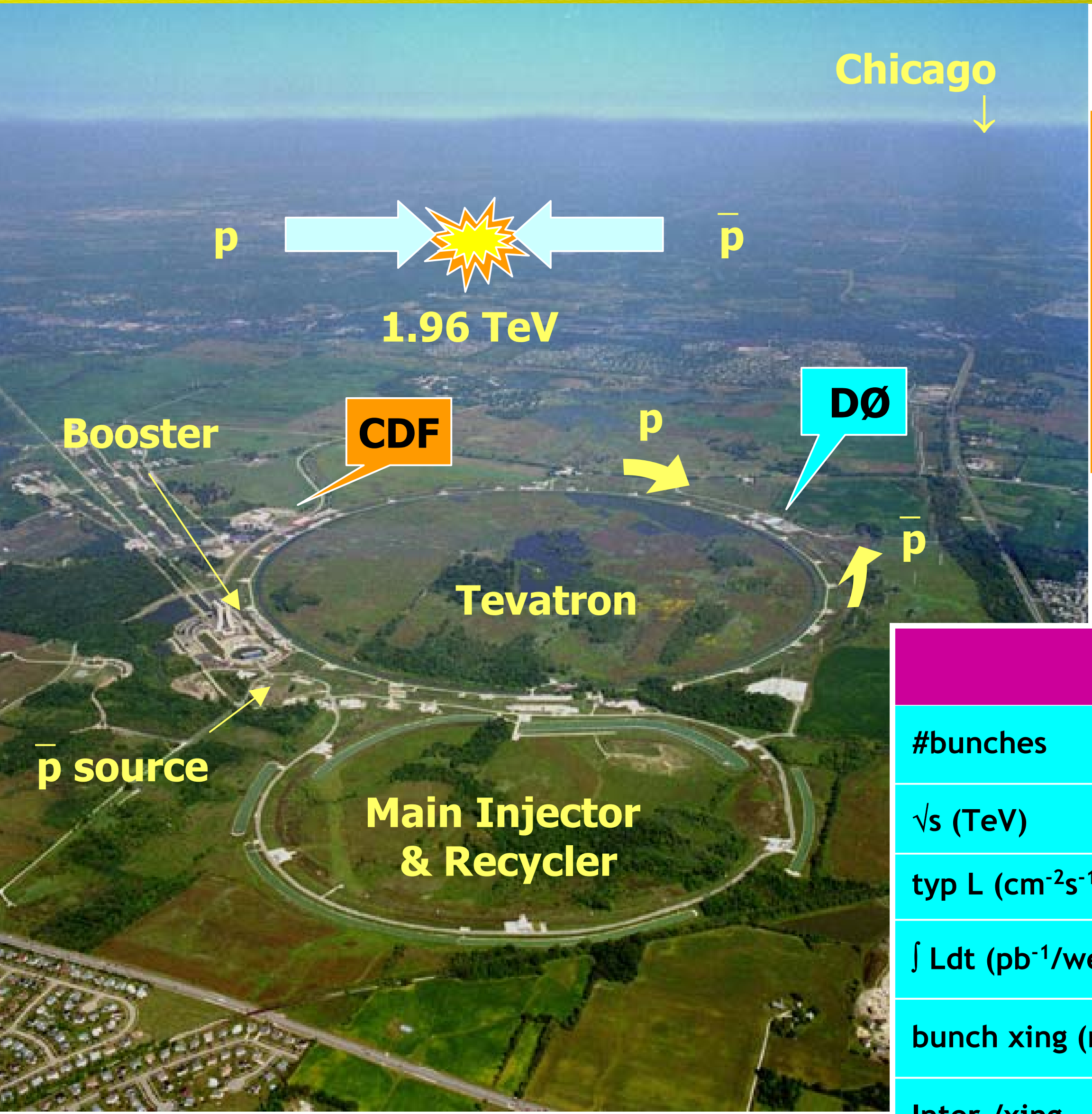
Alan L. Stone

Louisiana Tech University

...on behalf of the DØ Collaboration

- Tevatron Upgrade
- DØ Detector Upgrade
- Run 2 EW Physics Prospects
- Preliminary Analysis
- Summary & Goals

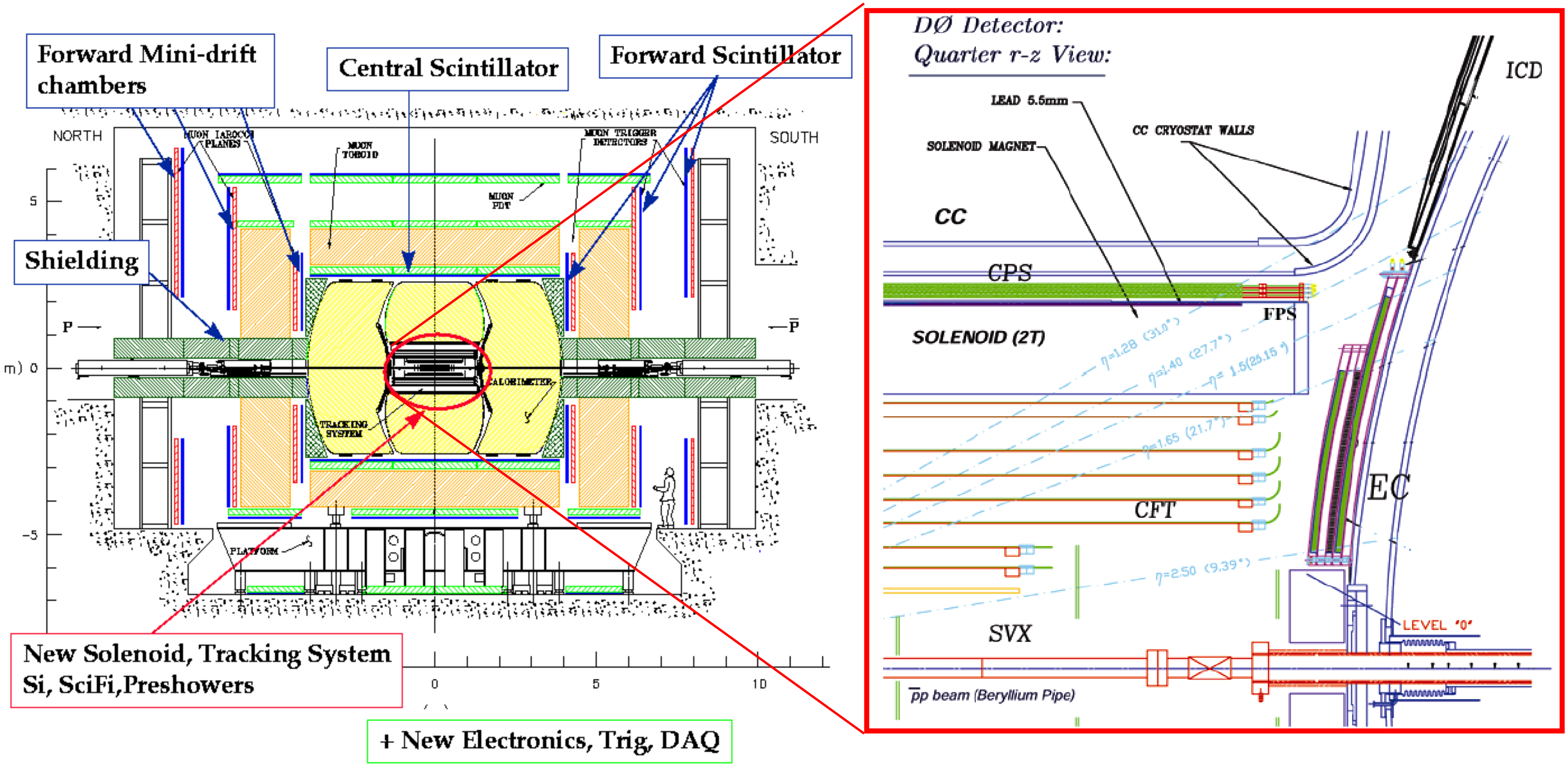
Run 2 Tevatron Upgrade



- Higher Energy
  1.8 TeV → 1.96 TeV
- Increased Luminosity
  0.1 fb^{-1} → 2 fb^{-1} → 15 fb^{-1}

	Run 1b	Run 2a	Run 2b
#bunches	6x6	36x36	140x103
√s (TeV)	1.8	1.96	1.96
typ L ($cm^{-2}s^{-1}$)	1.6×10^{30}	8.6×10^{31}	5.2×10^{32}
∫ Ldt (pb^{-1}/week)	3.2	17.3	105
bunch xing (ns)	3500	396	132
Inter./xing	2.5	2.3	4.8

The Run 2 DØ Detector



- Builds on the firm foundation of the Run 1 calorimeter and central muon system
- Adds magnetic tracking, silicon, new forward muon system, new electronics and three level trigger
- Electroweak analyses make use of the full detector capabilities

Run 2 Detector Performance

- Muon System
  - reduced backgrounds and trigger rates with additional shielding
  - lower thresholds (no prescale): single muon p_T > 7 GeV, dimuon p_T > 2 GeV
- Calorimeter
  - performance at $5x10^{32}$ cm^{-2} s^{-1} comparable to Run I performance at $2x10^{31}$ cm^{-2} s^{-1}
  - ability to *in situ* calibrate (*E* vs *p* now available)
- Preshowers
  - electron ID (central and forward)
  - forward electron triggering: additional x3-5 rejection over calorimeter alone
- Triggering
  - increased bandwidth: 7 MHz L1, 10 kHz L2, 1 kHz L3, 50 Hz to tape
  - more than an order of magnitude improvement over Run 1 system

- **Important additions to DØ physics capabilities:**

✓ E/p matching for electron identification

✓ Improved muon momentum resolution

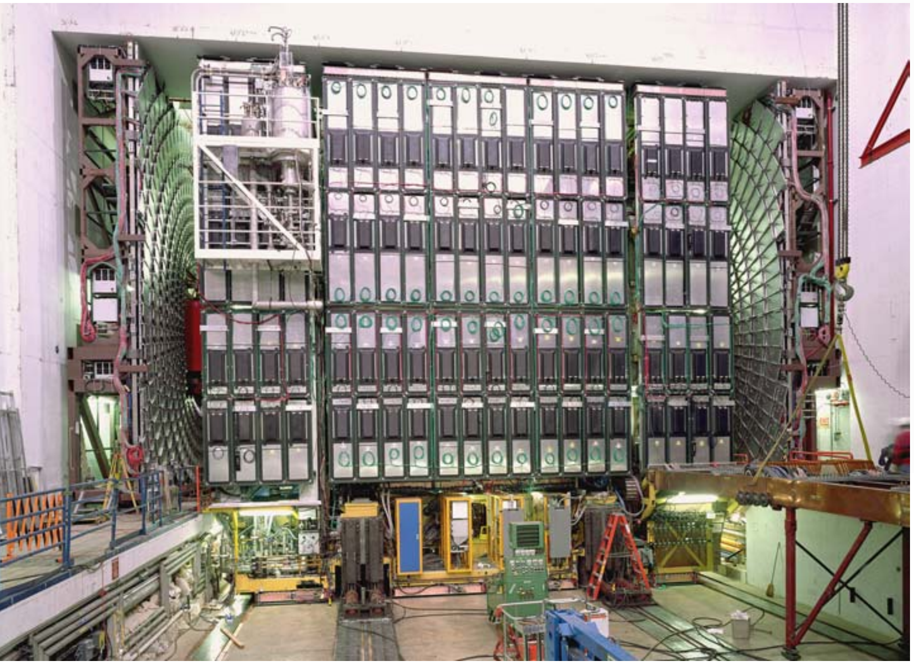
✓ Charge sign & momentum determination

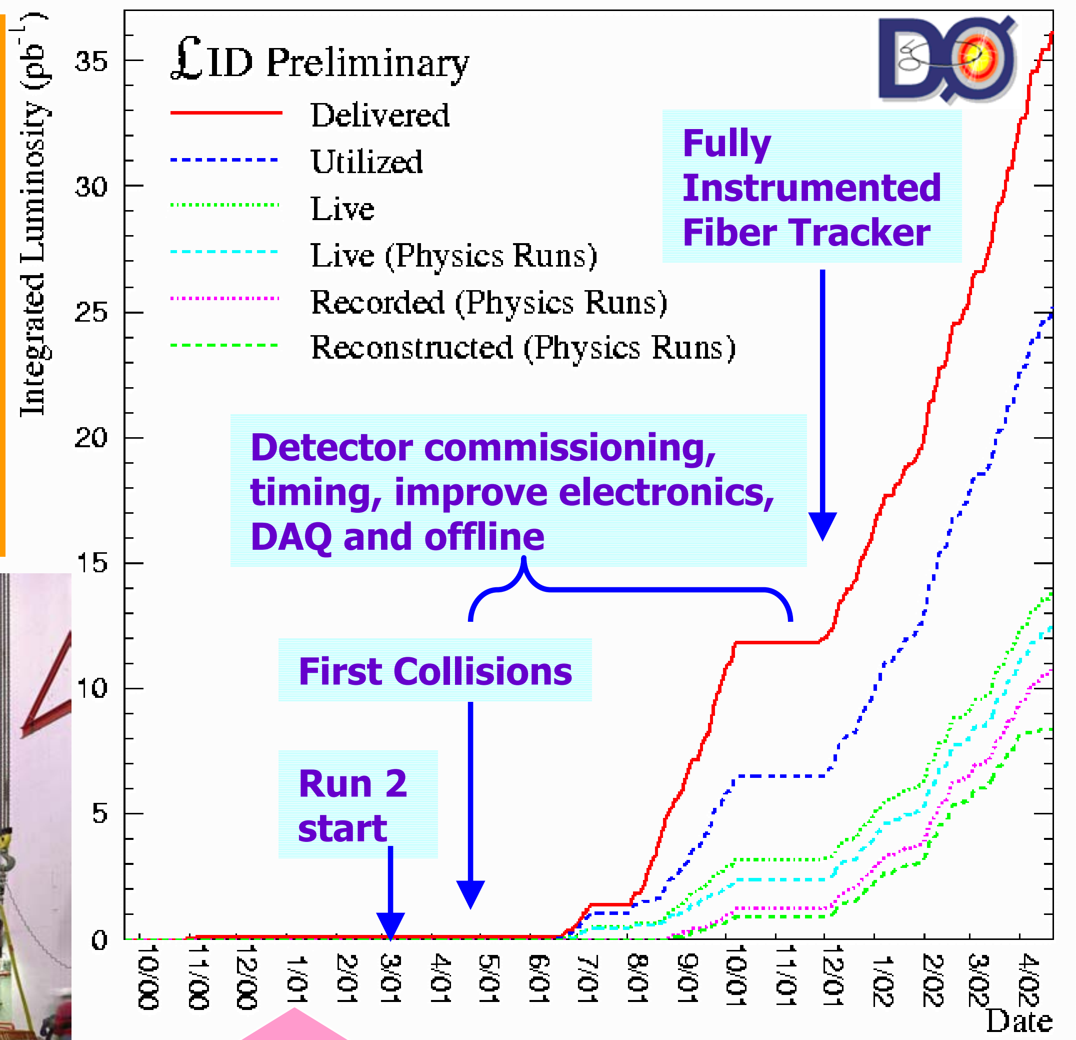
✓ Calorimeter calibration

✓ Displaced vertex identification

Data Recorded by the DØ Detector

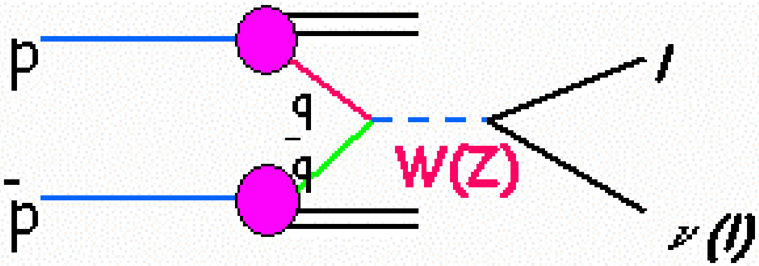
- ~40 pb^{-1} delivered by May 2002
- About 25 pb^{-1} used for detector commissioning
  - Timing, triggering
  - Data Acquisition System
  - Tracking, Alignment
  - object ID: e, μ, τ, γ, W, Z
  - E/p, $\not{E}_T$, jets, etc.
- Starting to do physics…





Detector Roll-in

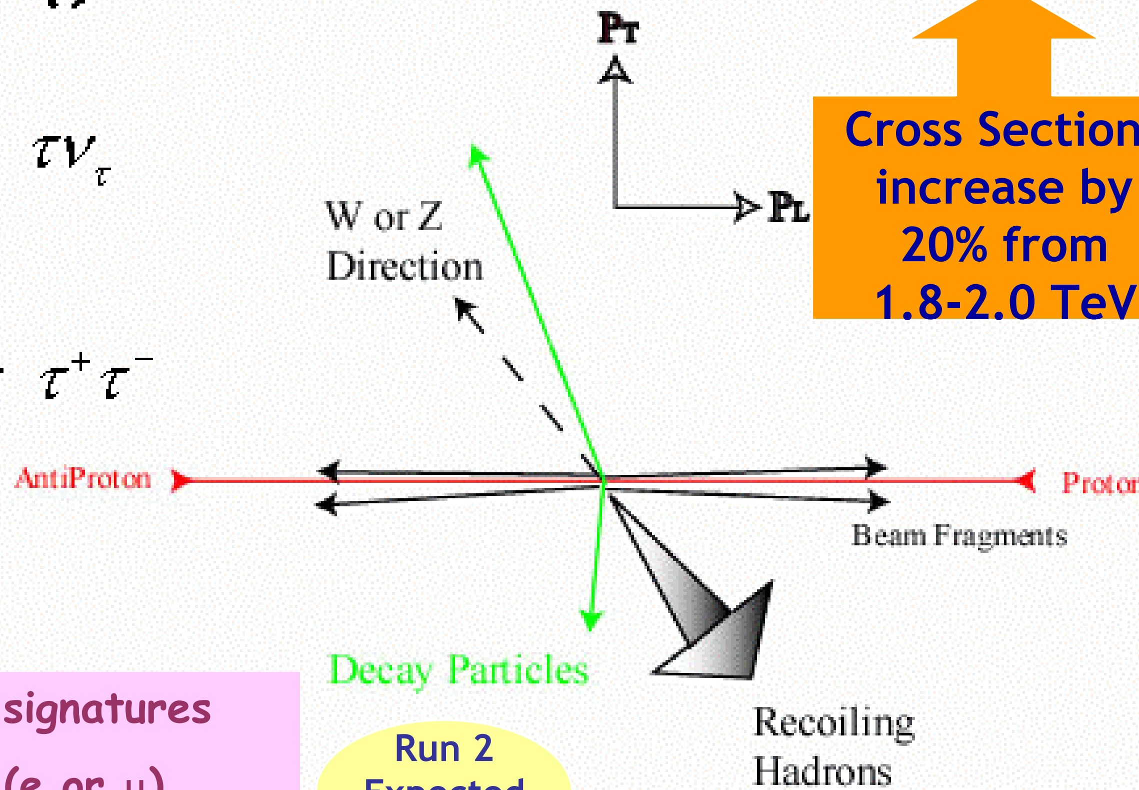
General Features of W & Z Production



$$\sigma\left(p\bar{p} \rightarrow W + X \rightarrow \ell\,\nu + X\right) \approx 2\ \text{nb}$$
$$\sigma\left(p\bar{p} \rightarrow Z + X \rightarrow \ell\,\bar{\ell} + X\right) \approx 0.2\ \text{nb}$$

Cross Sections increase by 20% from 1.8-2.0 TeV

$$W^{\pm} \xrightarrow{10.6\%} e\,\nu_e,\ \mu\,\nu_\mu,\ \text{or}\ \ \tau\,\nu_\tau$$
$$\xrightarrow{68.5\%} q\bar{q}'$$
$$Z^0 \xrightarrow{3.4\%} e^+e^-,\ \mu^+\mu^-,\ \text{or}\ \ \tau^+\tau^-$$
$$\xrightarrow{20.0\%} \nu\bar{\nu}$$
$$\xrightarrow{69.9\%} q\bar{q}$$



Distinctive lepton decay event signatures

- High P_T isolated leptons (e or μ)
- One high P_T lepton + Missing E_T (W)
- Two high P_T leptons (Z)

Run 2 Expected Rates

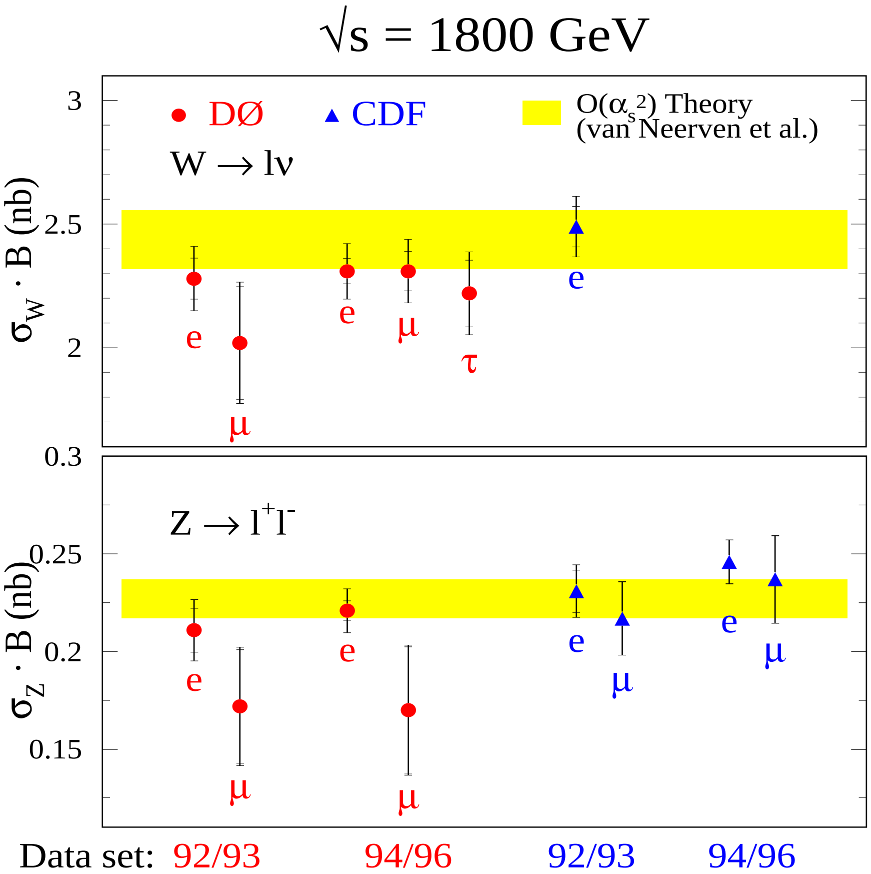
$W \rightarrow l\nu \ \Rightarrow \sim 1\ \text{Hz} \ @\ L = 2\times10^{32}$

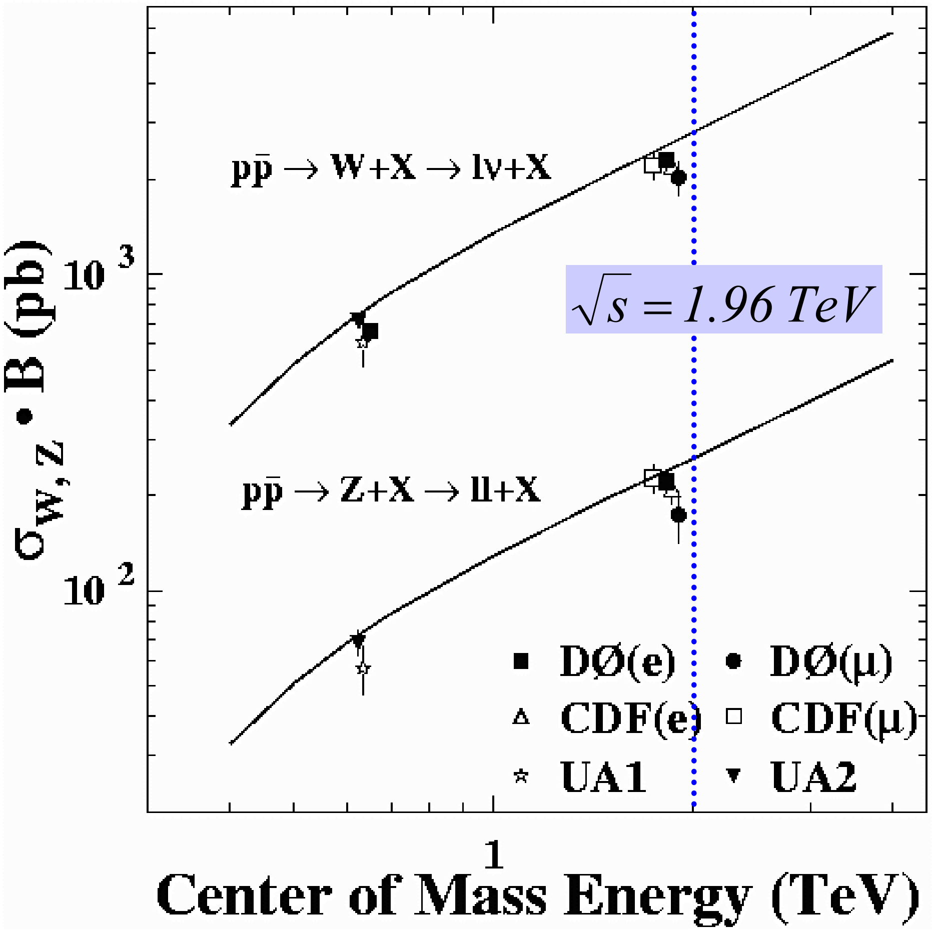
Run 2a EW Physics Prospects for DØ

- W & Z cross sections in electrons and muons
- W boson mass and width
- W charge asymmetry
- Trilinear gauge boson couplings
- W γ analysis and radiation zero
- Z' search

W & Z Cross Sections

Previous Tevatron results





- **Measurement errors:** Stat ⊕ Sys ~ 2%, Luminosity error ~ 4%
- **Theory error:** ~ 3%, NNLO, $O(\alpha_s^2)$ (Hamberg, van Neerven, Matsuura)

  Dominated by PDF's at NLO

Measurement of the *W* Width

Indirect Method

$$\sigma(p\bar{p} \to W + X) \times BR(W \to l\upsilon)$$

$$\sigma(p\bar{p} \to Z + X) \times BR(Z \to ll)$$

Measure

Deviations from the SM prediction would signal the presence of new decay modes of the W boson.

$$R \equiv \frac{\sigma(p\bar{p} \to W + X) \times BR(W \to l\upsilon)}{\sigma(p\bar{p} \to Z + X) \times BR(Z \to ll)}$$

$$= \frac{\sigma(W)}{\sigma(Z)} \times \frac{\Gamma(Z)}{\Gamma(Z \to ll)} \times \frac{\Gamma(W \to l\upsilon)}{\Gamma(W)}$$

Perturbative QCD

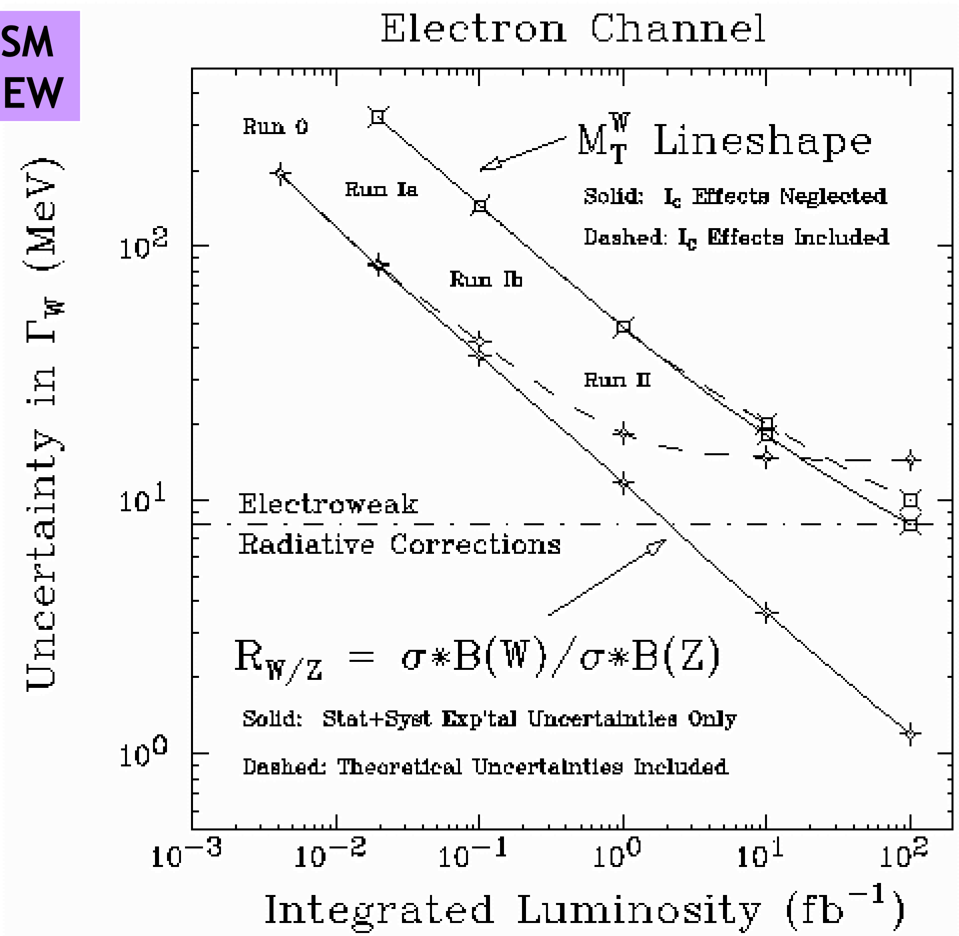
LEP

SM EW

W Width

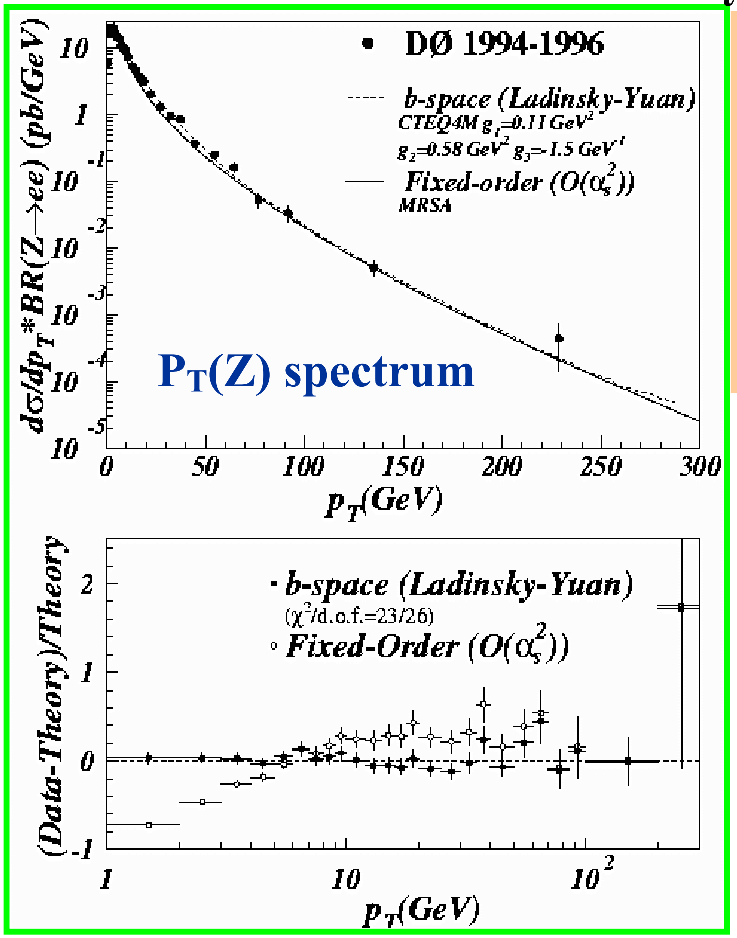
Direct Method

- Total width of *W* boson can be measured directly from the tail of the transverse mass distribution.
- Less model dependent than indirect method – dominated by Breit-Wigner, not detector effects.
- The lineshape measurement would yield better results with luminosity greater than 15 fb^{-1}.

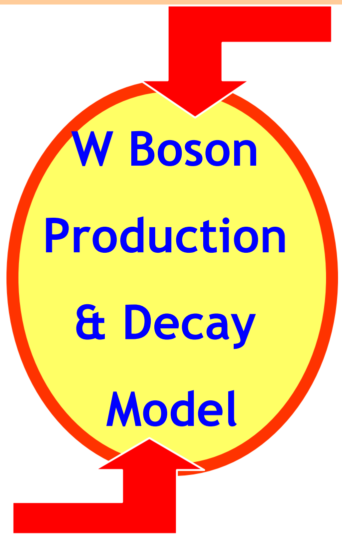


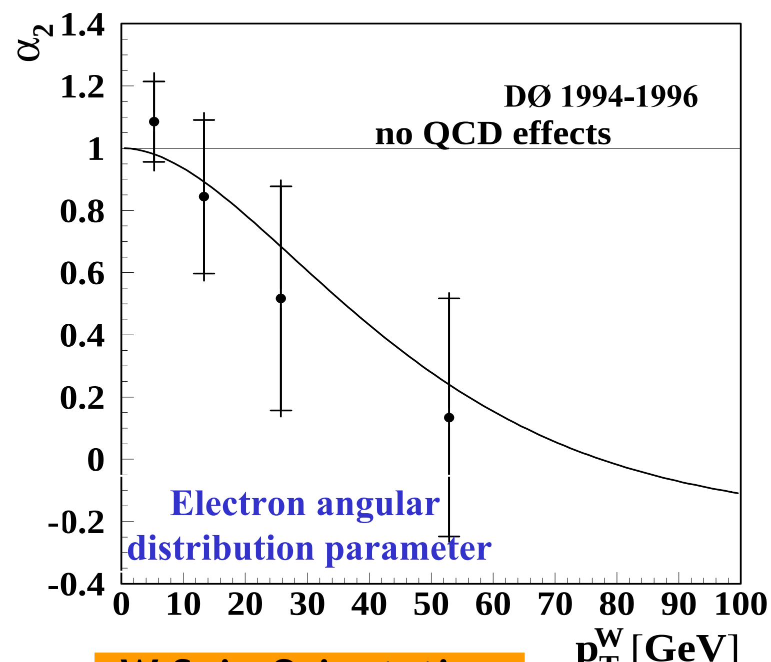
W Boson Mass Preliminaries

Theoretical calculations tuned by our measurements.



- Uncertainties in vector boson production at small p_T are a major source of uncertainty in mass of *W* boson
- Z: Similar production characteristics & decay e^+e^- very well measured - constrain Z/W prod. models
- Probe non-perturbative, resummation & fixed-order QCD effects (all values of p_T)
- Good agreement w/ Ladinsky-Yuan parameterization

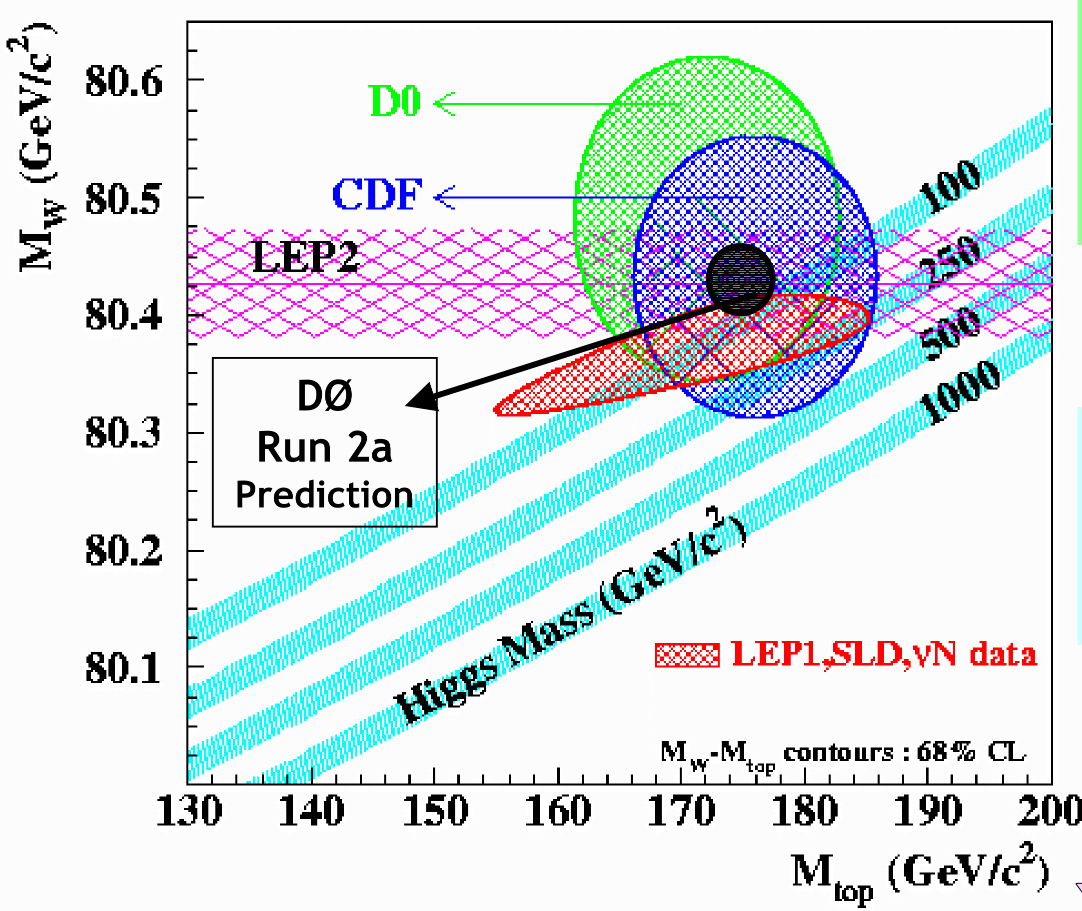




W Spin Orientation
E. Mirkes (1992)

- Probe effects of NLO QCD corrections on the spin structure of W boson production
- Transverse mass of W boson is correlated with the decay angle of the lepton

W Boson Mass



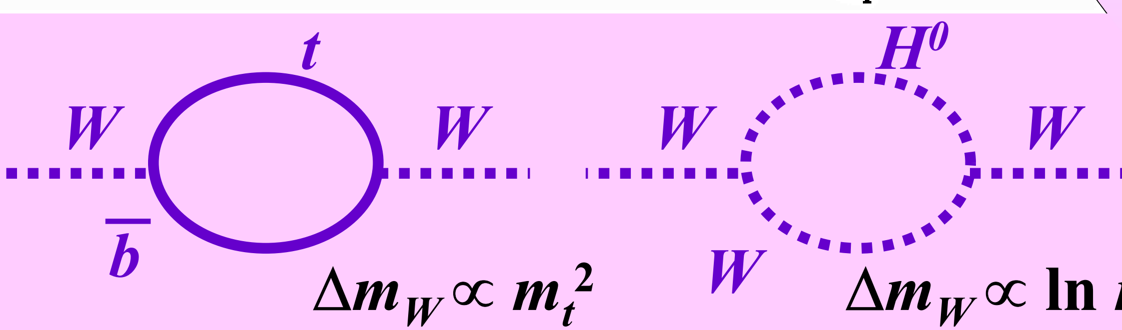
- EW symmetry breaking gives mass to the *W* boson
- Aside from radiative corrections Δr_{EW}, *W* boson mass is determined by three precisely measured quantities: M_Z, G_F and α

$$M_W = \left(\frac{\pi\alpha(M_Z^2)}{\sqrt{2}G_F}\right)^{\frac{1}{2}} \frac{1}{\sin\theta_W\sqrt{1-\Delta r_{EW}}}$$

- Derive the size of Δr_{EW} from the measured *W* boson mass
  - ✓ Dominated by loops involving the top quark & Higgs boson

- Precision measurement of *W* mass of ~30 MeV/c² with 2 fb⁻¹ of Run 2a data should be possible

- With a precision of 20 MeV/c² for the *W* mass and 2 MeV/c² for the top quark mass (Run 2b, 15 fb⁻¹), the Higgs Boson mass can be further constrained.



$\Delta m_W \propto m_t^2$ $\qquad$ $\Delta m_W \propto \ln m_H$

W Charge Asymmetry

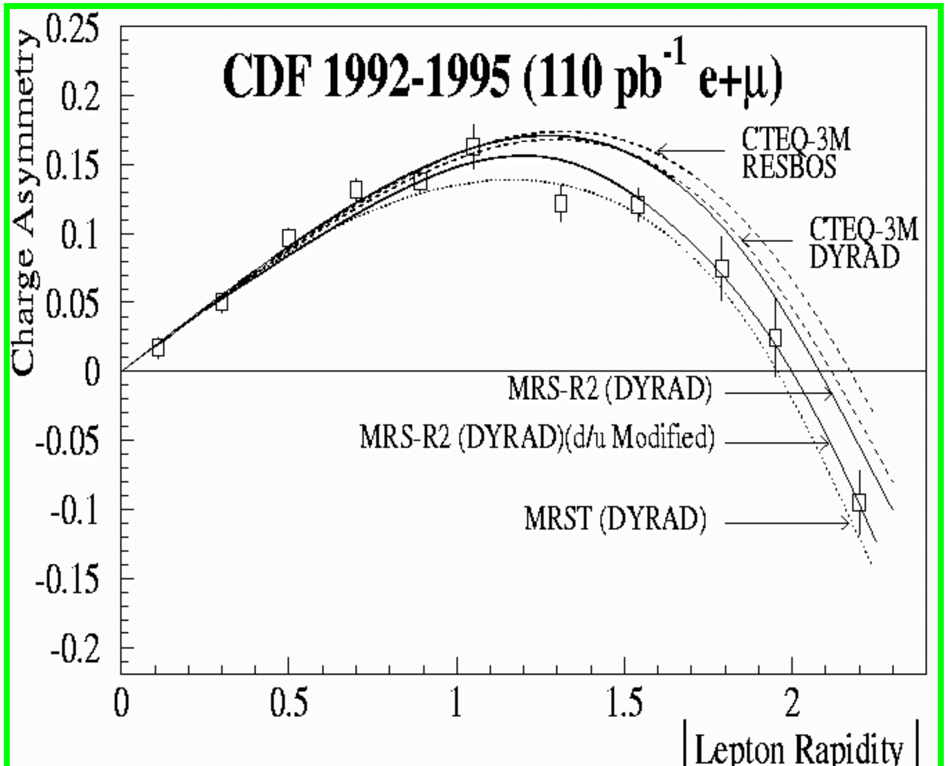
$$A_W(y) = \frac{\frac{d\sigma(W^+)}{dy} - \frac{d\sigma(W^-)}{dy}}{\frac{d\sigma(W^+)}{dy} + \frac{d\sigma(W^-)}{dy}}$$

Efficiencies & acceptances cancel out

W charge asymmetry is inferred from the lepton rapidity asymmetry.

$$A(y_l) = \frac{l^+ - l^-}{l^+ + l^-}$$

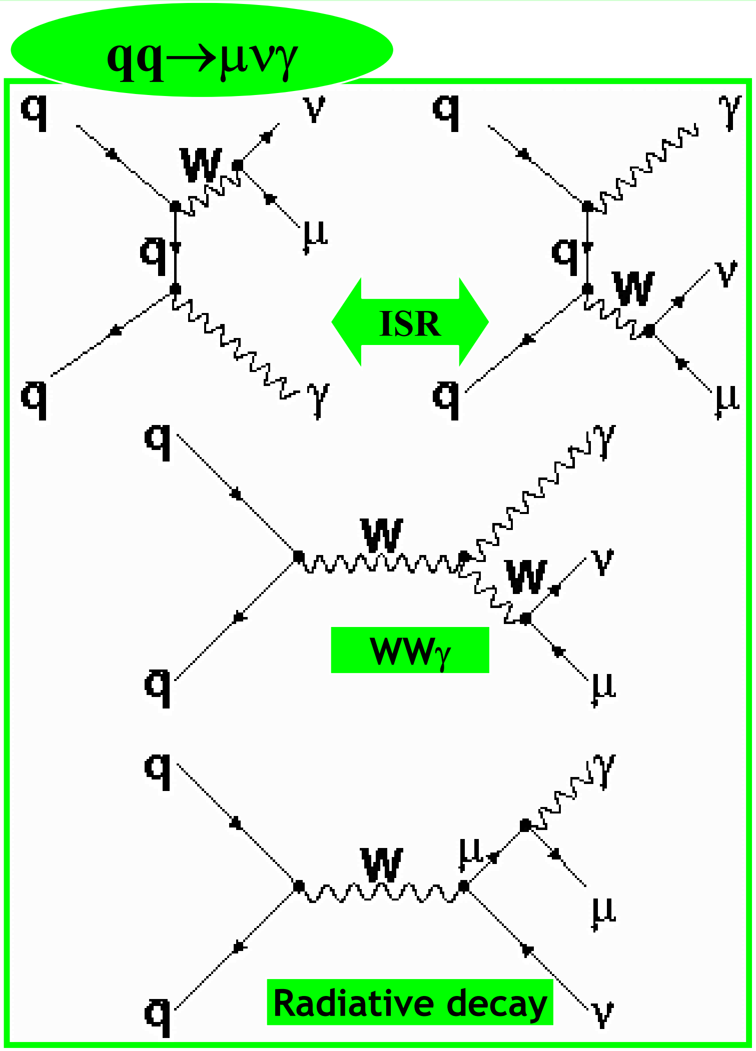
$A_W(y)$ is closely related to the slope of the $d(x)/u(x)$ quark distribution at high Q^2 ($\approx M_W^2$)



- *W* bosons are produced primarily by the annihilation of *u* ($\bar{d}$) quarks from the proton and *d* ($\bar{u}$) quarks from the antiproton
- *u* quarks tend to carry more momentum than *d* quarks, so the W^+ (W^-) is boosted in the proton (antiproton) direction
- A precision *W* charge asymmetry measurement will discriminate between PDFs
- Reduce uncertainty from PDFs in the *W* mass measurement

Gauge Boson Self-Interactions

Leading order tree level Feynman diagrams



We investigate properties of vector boson pair production $W^{\pm}\gamma$, $W^{+}W^{-}$, $W^{\pm}Z$ in various final states in order to test the nonabelian couplings of photons, Z's and W's

Trilinear coupling diagrams are involved in vector boson pair production.

SM makes specific predictions for the strength of the couplings.

$WW\gamma$ & WWZ anomalous couplings are related to the EM multipole moments of the W

$\mu_W = e(1+\kappa + \lambda)/2M_W$ $\quad$ $q^e_W = -e(\kappa - \lambda) / M^2_W$

…where $\Delta\kappa = (\kappa-1) = \lambda = 0$ in SM

From MC cross section calculations: with non-SM couplings, the trilinear diagram contribution becomes larger with larger anomalous couplings By counting $W\gamma$ events & measuring the cross section, the coupling effect can be measured

'Anomalous' couplings represent possible deviations from the SM predictions.

Anomalous Coupling Limits

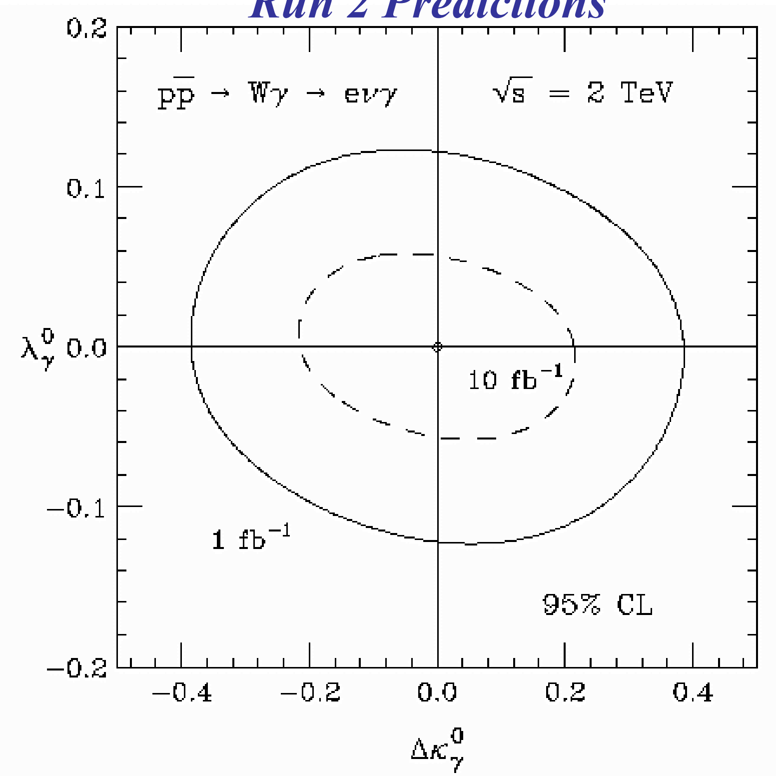
Run 1: Anomalous coupling limits from combined DØ results of *Wγ*, *WW* and *WZ* cross section measurements (equal γ +Z couplings)

Run 1

$$-0.25 \le \Delta\kappa \le 0.31 \ (\lambda = 0)$$

$$-0.18 < \lambda < 0.18 \ (\Delta\kappa = 0) \ \ at\ 95\%\ CL$$

Run 2 Predictions

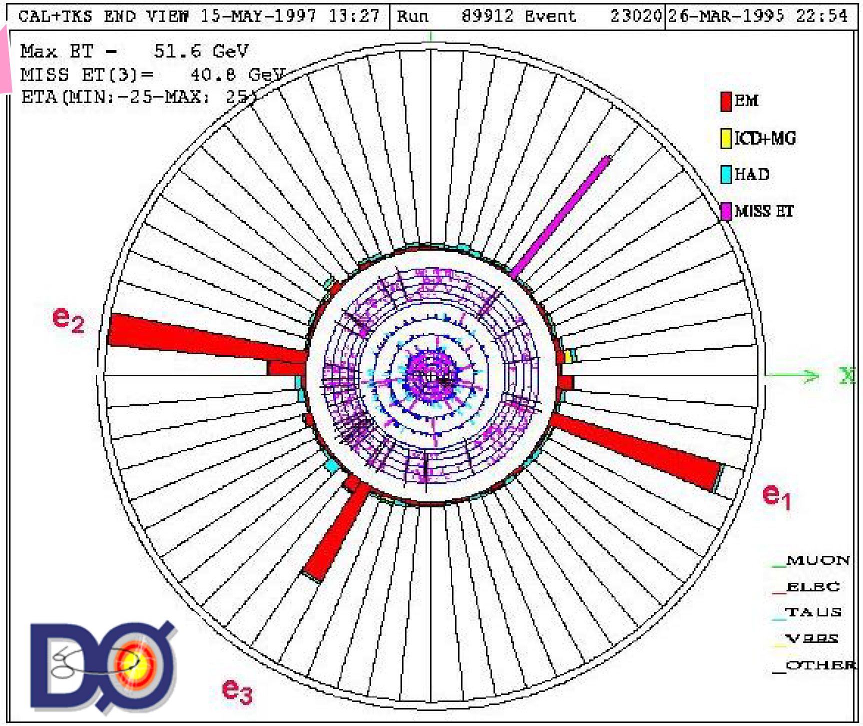


$$W \to e\nu$$

$$Z \to e^+e^-$$

$M_T(e_2,\nu)$=74.7 GeV/c²
$M(e_1,e_3)$=93.6 GeV/c²

Run 1

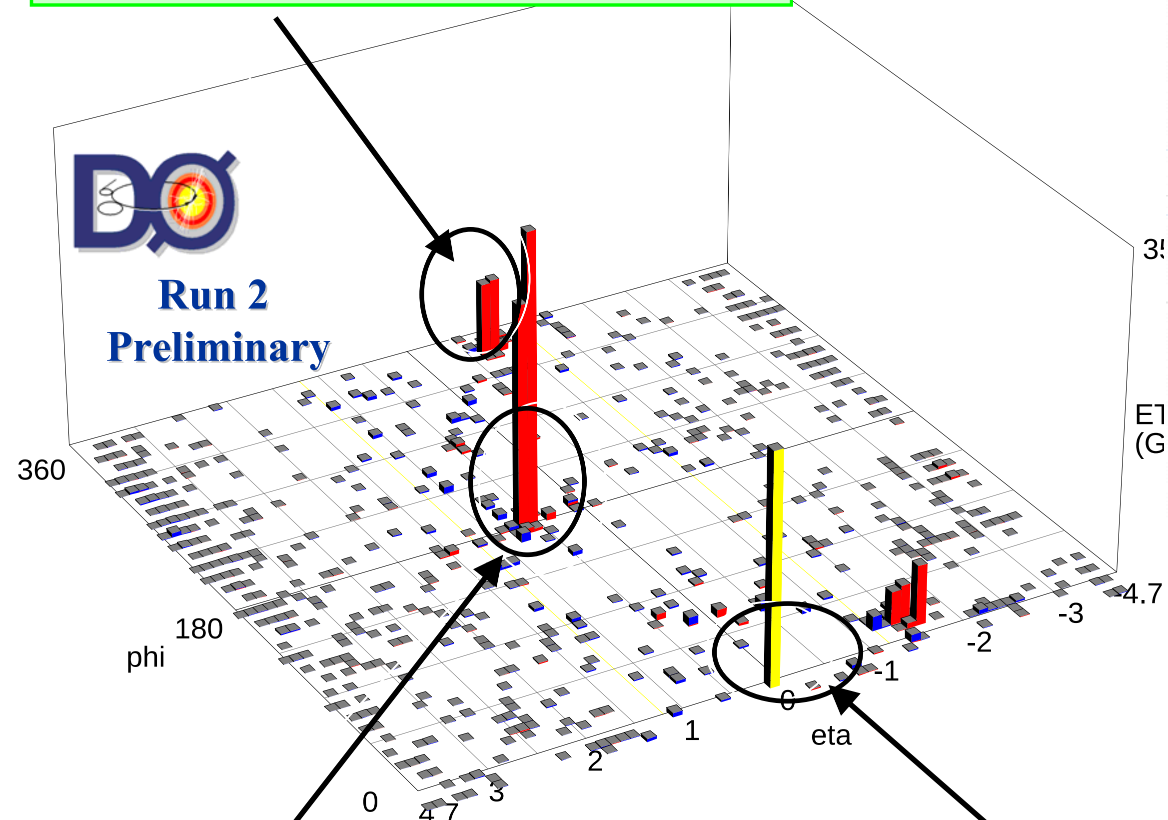


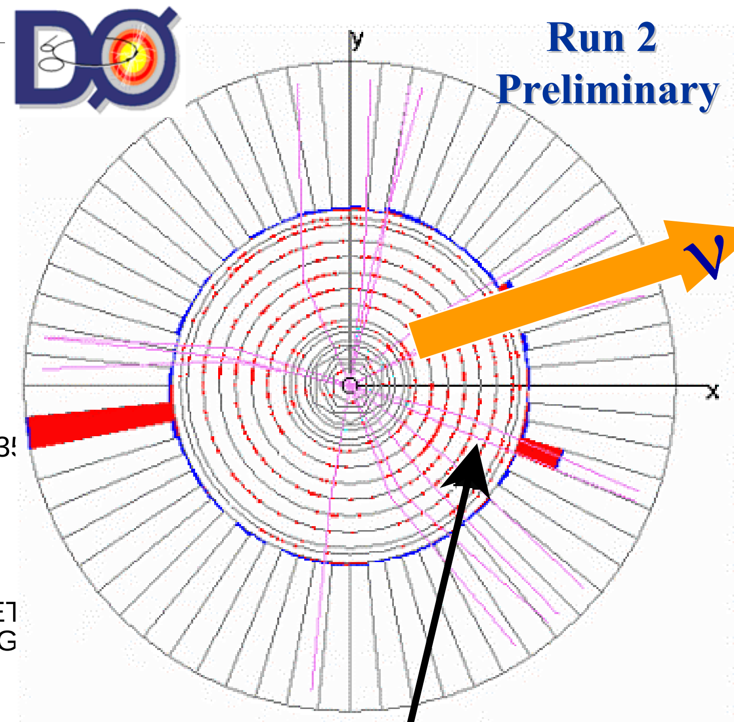
- Expect ~2000 Wγ events in Run 2a
- Improve by 2-3x over Run 1 limits

$W\gamma$ Candidate

Run 142851 Event 3622988 Tue Apr 16 16:39:13 2002

Electron, p_T = 20 GeV/c



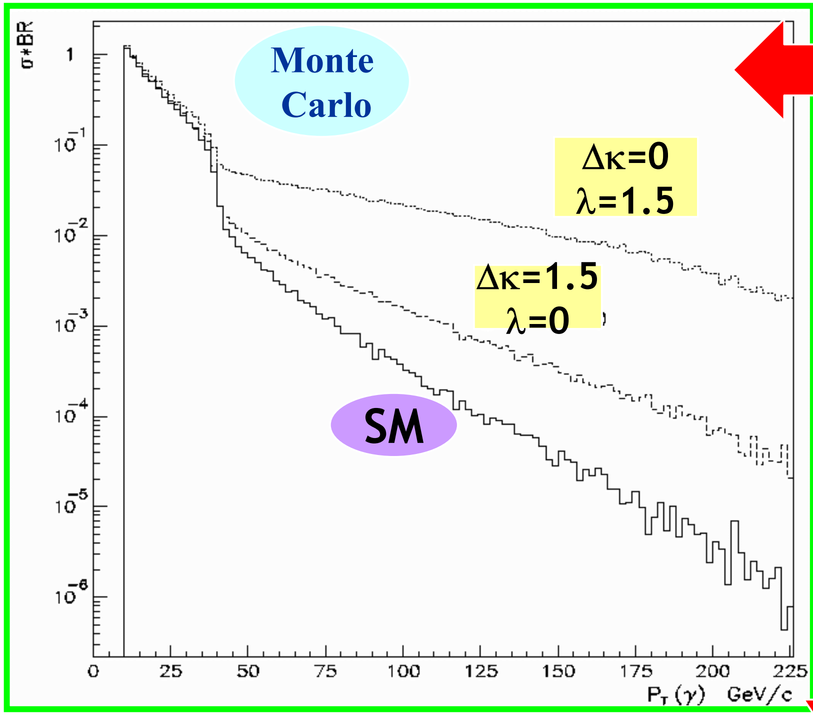


Track match to an electron

Photon, p_T = 58 GeV/c

ME_T = 24.8 GeV

Radiation Amplitude Zero

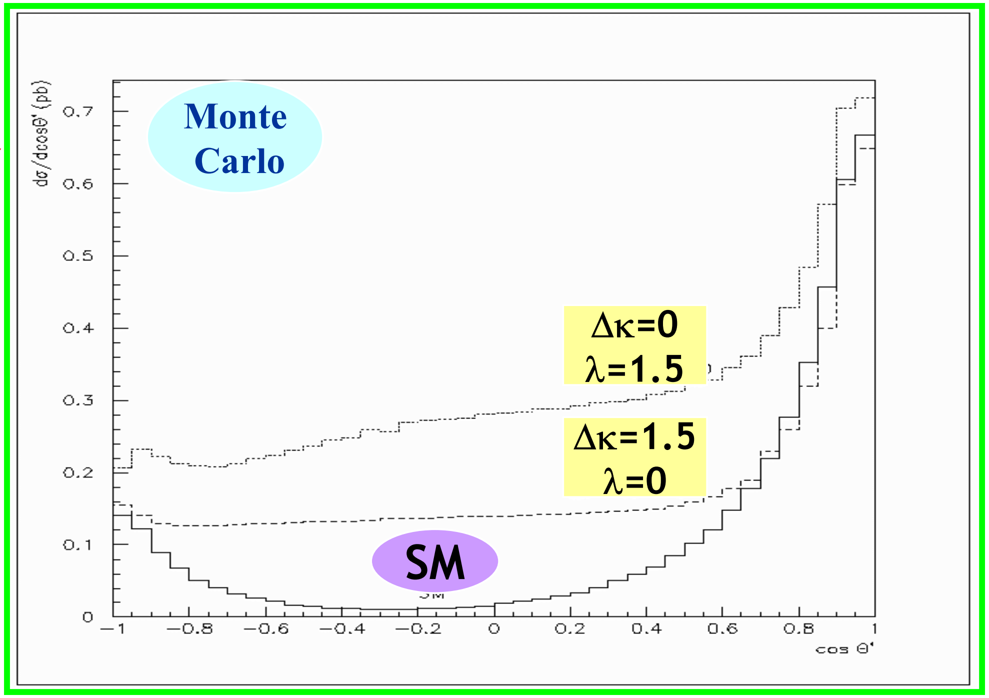


- Extra coupling between the *W* & γ leads to excess of events, visible at high E_T.

Due to the interference of the different SM diagrams, the *W*γ differential cross section vanishes at a particular point in phase space, called the *'radiation zero'*

Cos θ^* = -1/3(+1/3) for $W^+(W^-)$

…θ^* is the scattering angle of the photon relative to the quark direction in the *W*γ CM rest frame



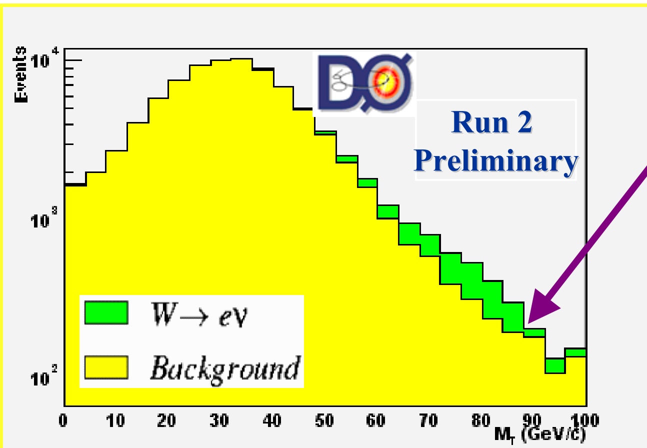
- Effect of the anomalous couplings is to fill in the zero.
- Never before observed.

$W \rightarrow e\nu$ Event Sample

Track matching necessary to disentangle overwhelming QCD background

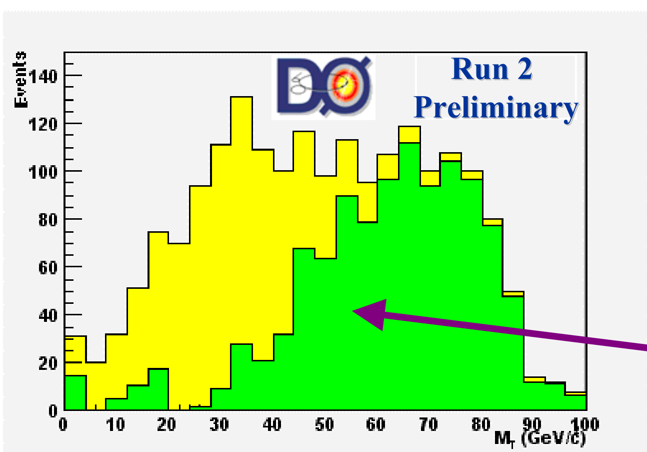
Background subtracted

No Track Matching



Events

M_T (GeV/c^2)



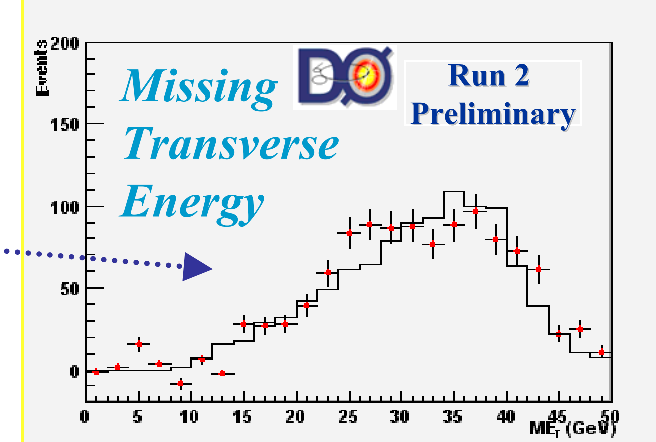
Events

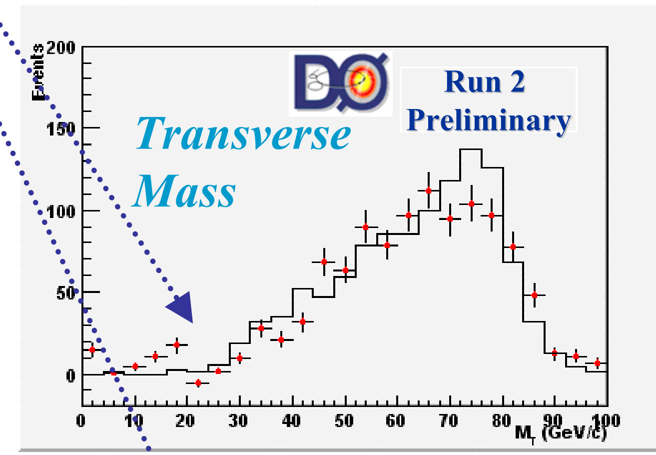
M_T (GeV/c^2)

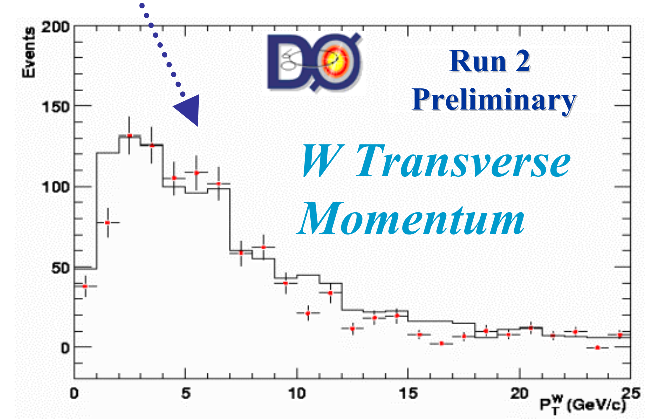
With Track Matching

Major source of background:

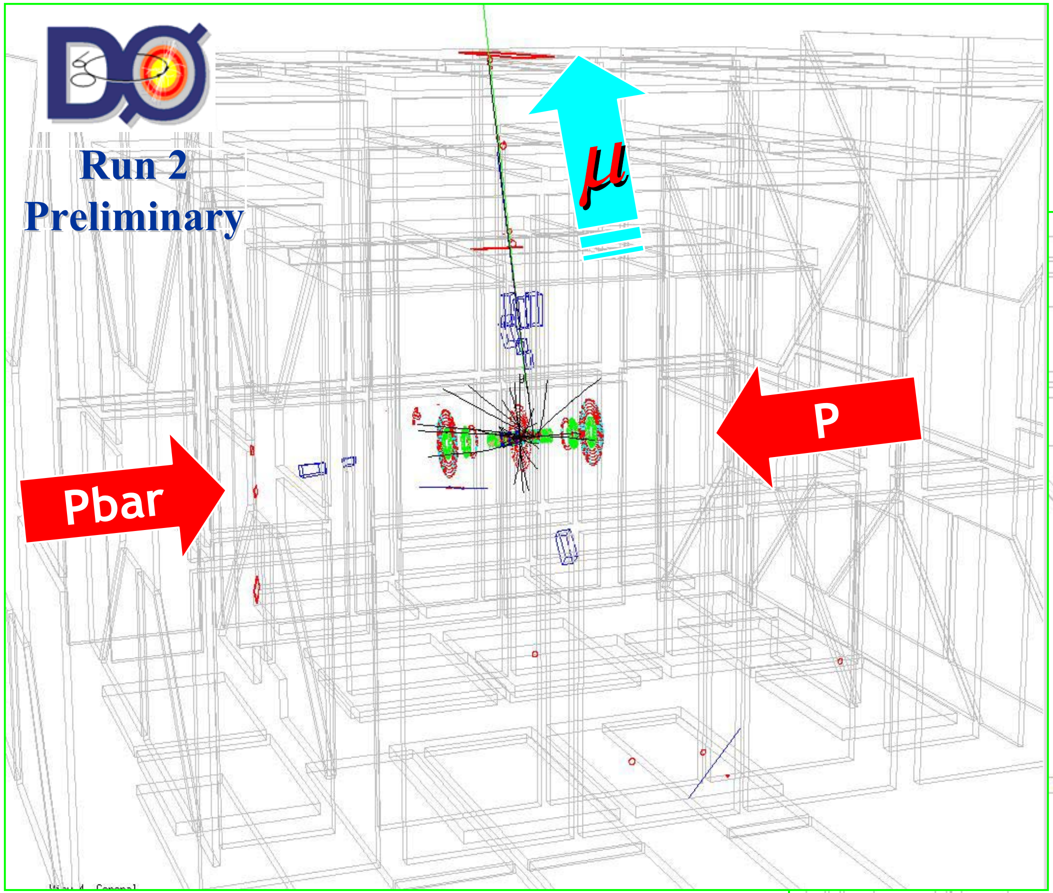
- dijet events where one jet passes EM id cuts & the ME_T is mismeasured.
- Also: $W \rightarrow \tau\nu$, $Z \rightarrow ee$ & ttbar.



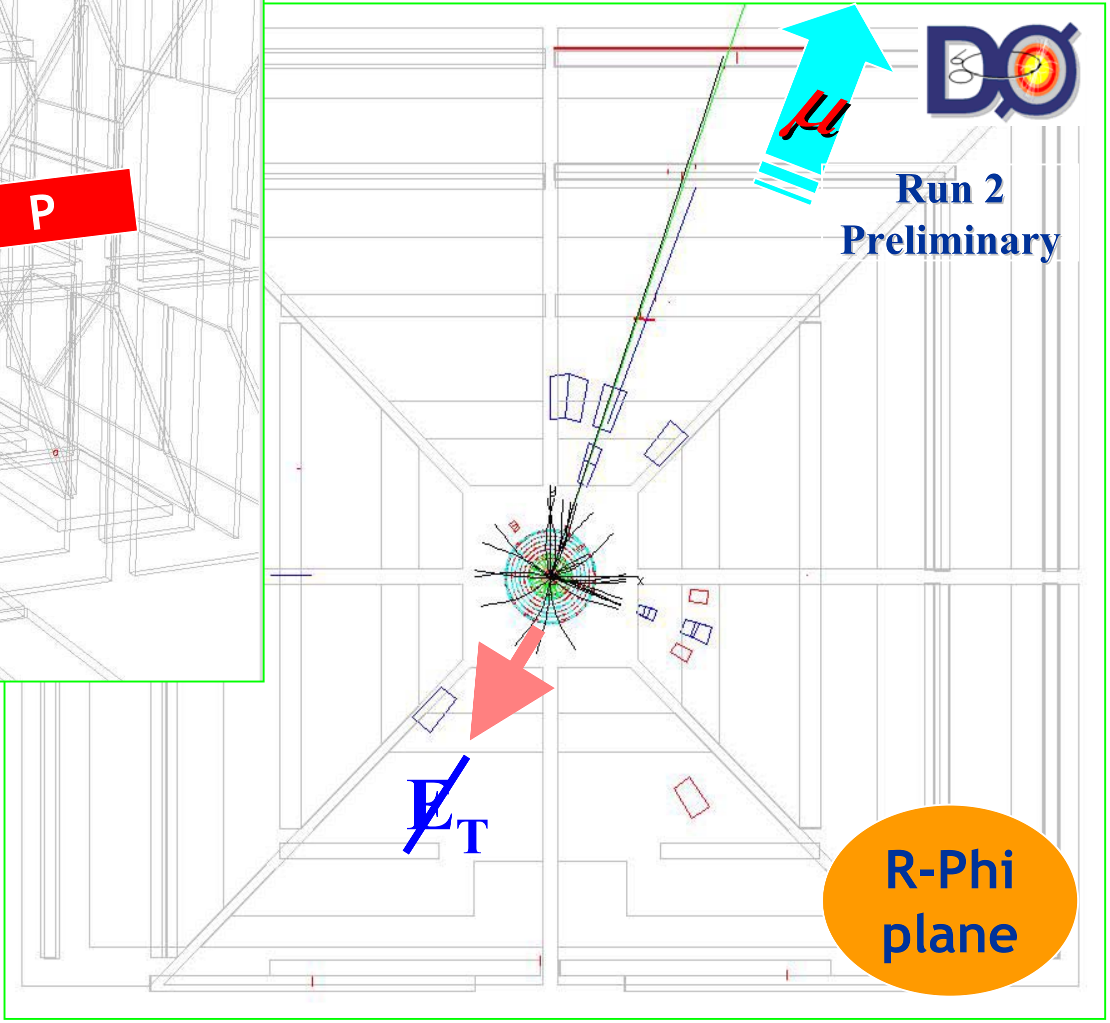




$W \rightarrow \mu\nu$ Event Candidate



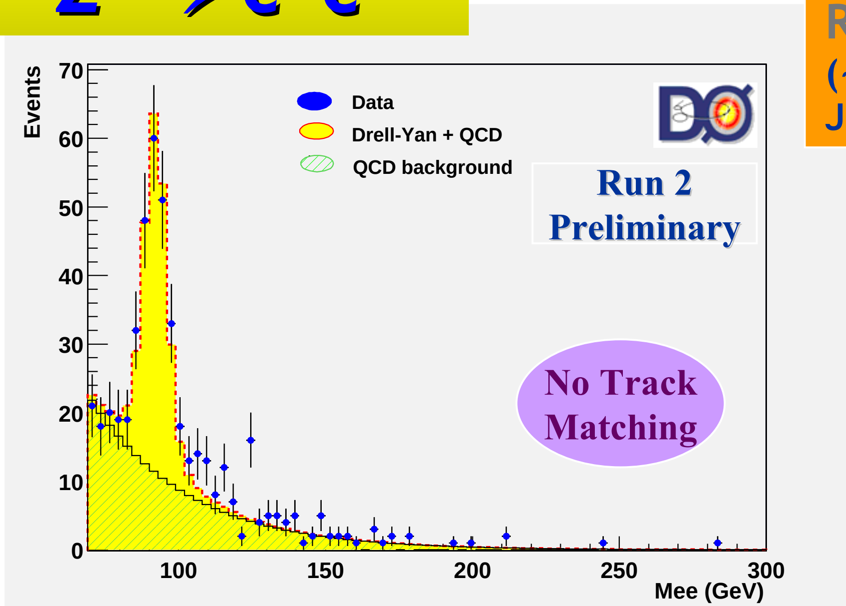
Central track matched to muon
- Transverse Mass = 78 GeV
- 11 Hits & DCA = 50μm

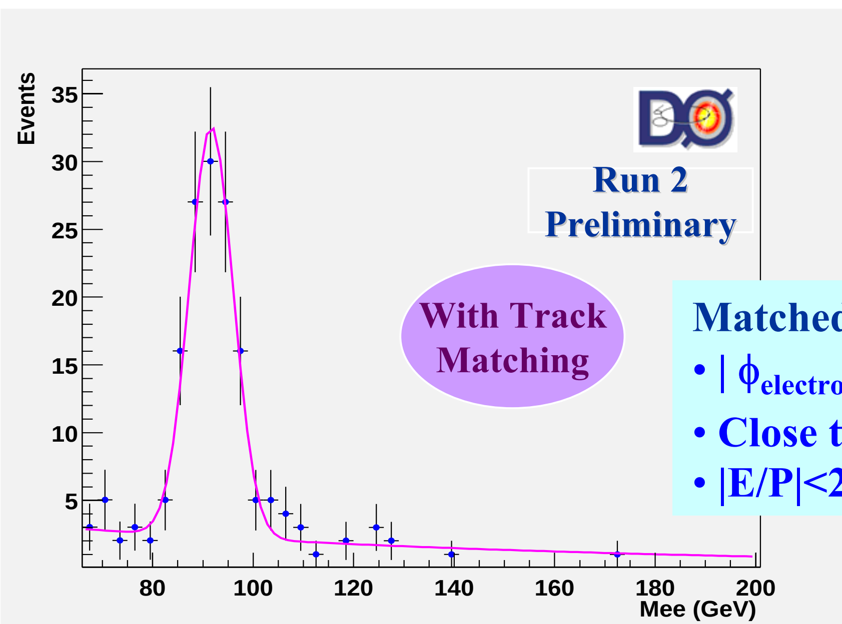


Muon p_T = 37 GeV
Charge = -1
2.6 GeV (MIP) in Calorimeter

$Z \rightarrow e^+e^-$

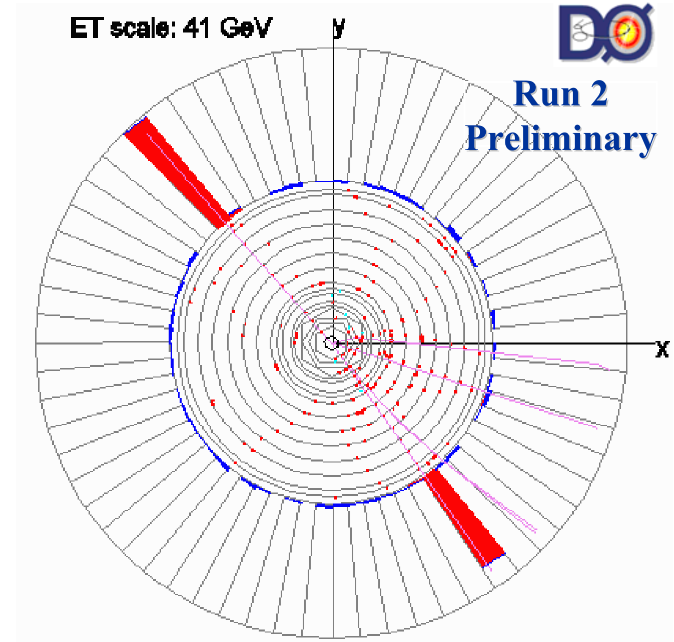
Preliminary Run 2 data ($\sim$3 pb^{-1} from Jan-Mar 2002)

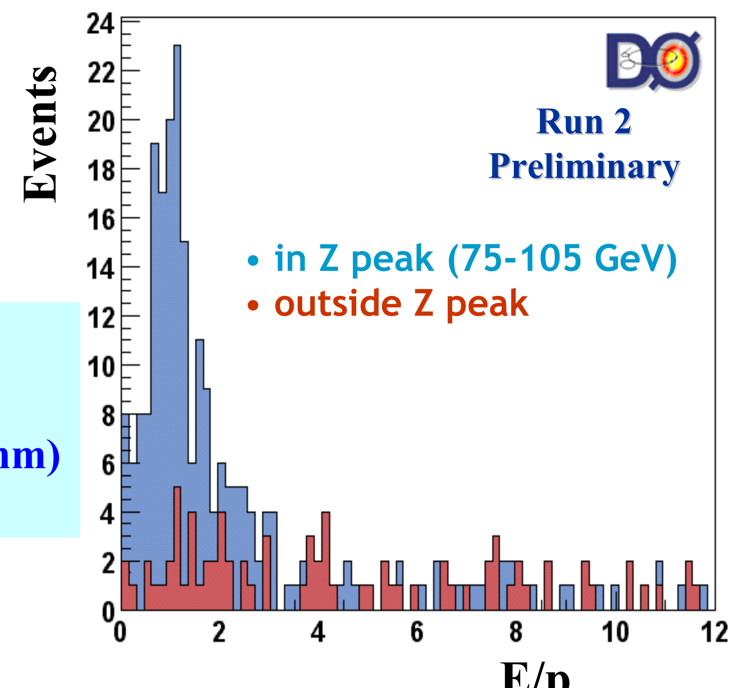




Matched track:

- $|\phi_{electron} - \phi_{track}| < 0.02$
- Close to vertex (< 1 mm)
- $|E/P|<2$

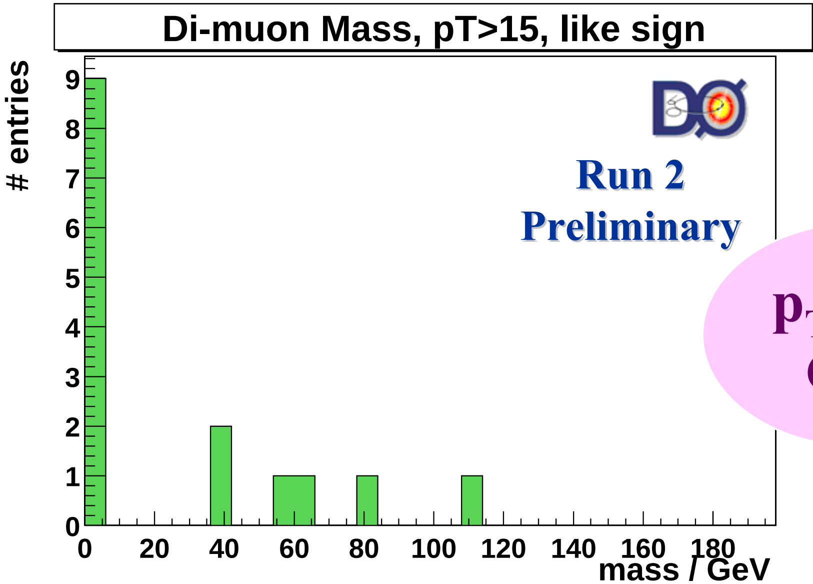


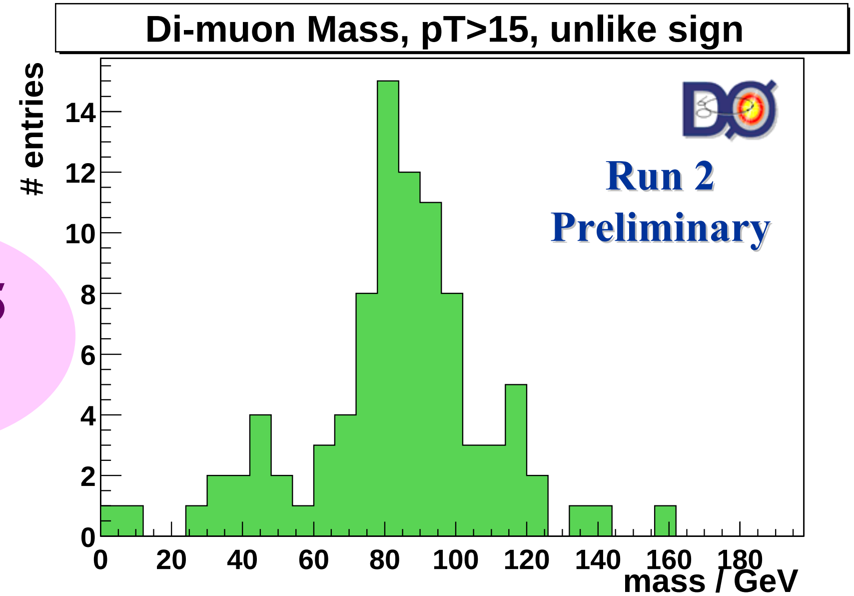


E/p

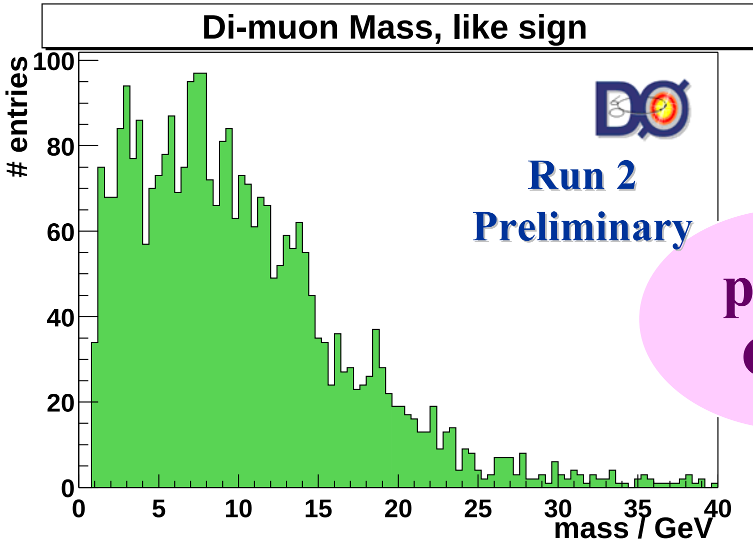
Di-Muon Mass Plots

Central track matched with muon

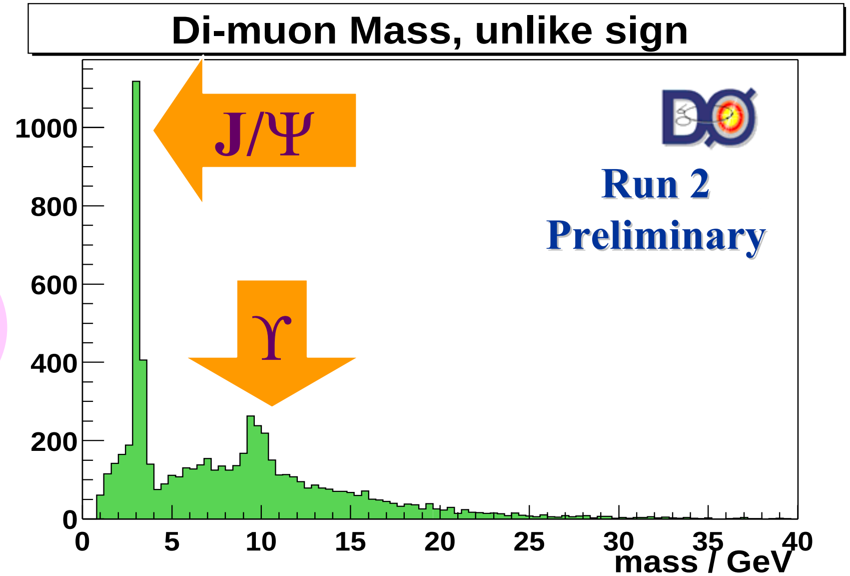




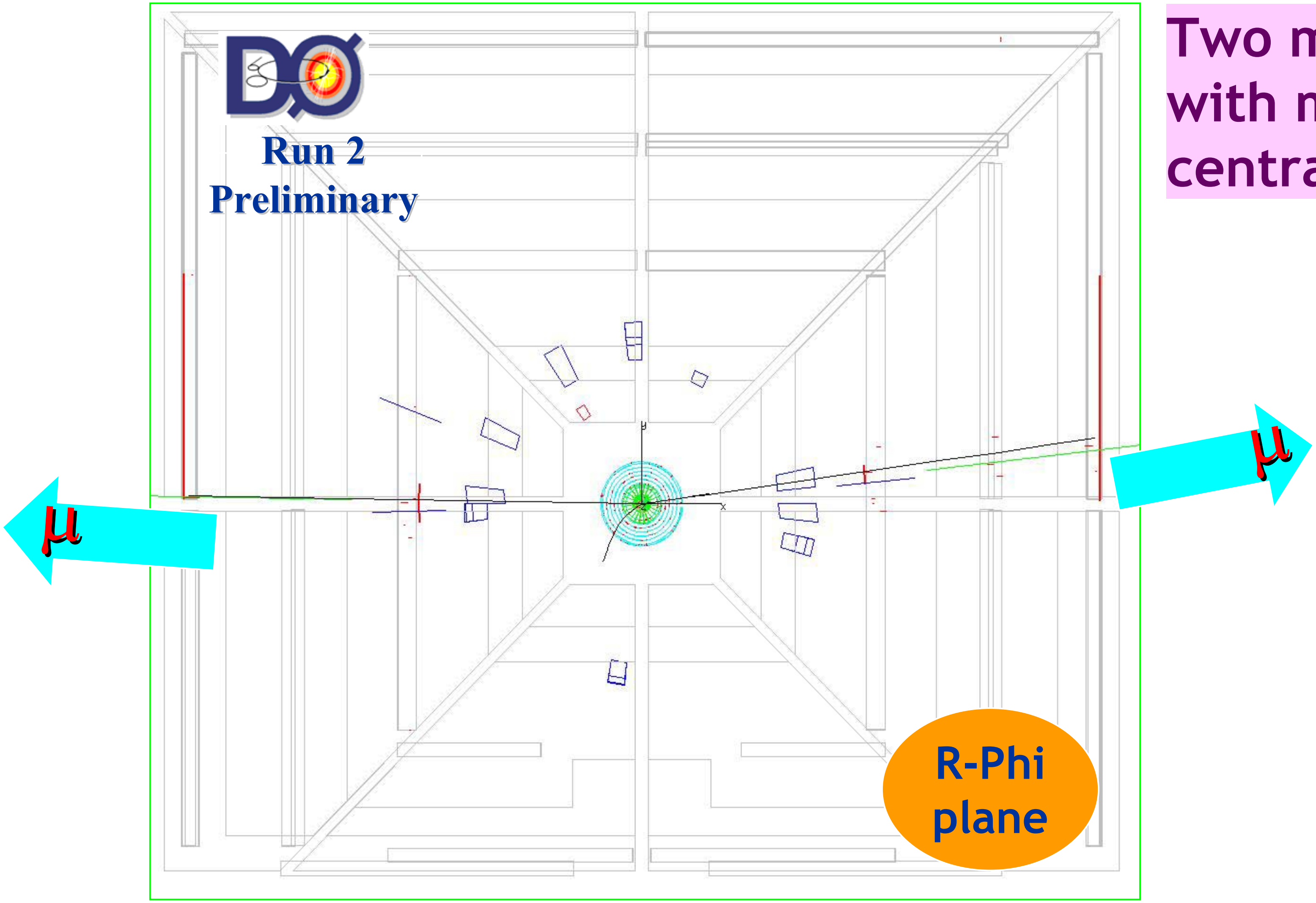
$p_T > 15$ GeV



$p_T > 2$ GeV



$Z \to \mu^+\mu^-$ Event Candidate



Two muons with matched central tracks

Invariant mass = 102.7 GeV

DØ Summary & Goals

- Improved DØ detector for Run 2
  - 2T solenoid, superior tracking, forward muon, faster electronics, three level trigger system
- We are reconstructing electrons, muons, jets, missing E_T, J/ψ, W's and Z's
  - Working hard to understand our backgrounds
- From Run 2a integrated luminosity of 2 fb^{-1}
  - A few million *W* & hundreds of thousands of *Z* events
  - Precision measurements of *W* mass & width
  - Cross sections at higher energy
  - Improve anomalous coupling limits & charge asymmetry measurements
  - QCD: *W* & *Z* transverse momentum measurements
  - Radiation zero
- We are on the way to exciting physics!